A SHORT TREATISE

ON THE

COMPOUND STEAM ENGINE,

WITH A

NEW METHOD OF FINDING THE RELATIVE AREAS OF THE TWO CYLINDERS.

ILLUSTRATED WITH DIAGRAMS, TABLES, ETC.

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THE COMPOUND ENGINE.

The compound engine—whatever diversity of opinion may be held by engineers and others as to its merits as an economical expansive engine—has attracted towards itself a very considerable share of attention, from the superior results that have been obtained by it in many instances; and it is reasonable to suppose that, when a certain degree of perfection has once been attained in the manufacture of any machine, or economy secured by any new arrangement of its parts, similar machines can be so constructed as to give out the same results, if proper care is taken that the same arrangement and construction is faithfully carried out as in that of the more perfect machine. And when that degree of economy has not been obtained from a compound engine which had reasonably been

expected, it would, no doubt, be found, if proper inquiry were made, that the fault lay, not in the principle that had been adopted, but that sufficient skill had not been exercised in properly proportioning the different parts through which the steam had to pass or come in contact on its way from the boiler to the condenser, and that sufficient means had not been employed to prevent or replace any waste of heat from condensation and other causes.

As the compound engine is being now so universally adopted in the Mercantile Marine Service, and a knowledge of its principles absolutely necessary by those engaged in attending it, we will, in the following remarks, explain these principles in as simple a manner as possible, and institute a comparison between the respective merits of the single-cylinder expansive condensing engine and the compound engine:

The compound engine is a high and low-pressure condensing engine, having two ordinary steam cylinders, the smaller or high-pressure cylinder communicating direct with the boiler, the larger or low-

pressure condensing cylinder direct with the condenser, and both with each other. The steam is admitted freely from the boiler into the high-pressure cylinder until the piston has been moved through a certain distance where the valve is so regulated that the communication with the boiler is entirely shut off, and the remainder of the space to be passed through by the piston is performed by the expansion of the steam now shut up in the cylinder, and which, after doing its work in this cylinder, passes on to the condensing cylinder, where it does an equal or proportionate quantity of work, and then passes into the condenser.

It has been found from modern practice that when the length of stroke of both cylinders is the same, it is necessary that the condensing cylinder be about three times greater in area than the high-pressure one, and this proportion is best suited when the steam employed is from 45 to 50 lbs pressure above the atmosphere, and cutting off the steam after being admitted during $\frac{1}{3}$ of the stroke in the high-pressure cylinder. When the steam to be employed is of a less

pressure, but the point of cut-off the same, then the relative proportions of the cylinders must be nearer to each other, and the reverse when steam of a greater pressure is to be used.

To get the maximum of economy out of any class of expansive condensing engine, the pressure of steam and point of cut-off must be so regulated that the steam passes into the condenser at the end of the stroke at a pressure not exceeding 5 lbs. above a perfect vacuum, and with steam at 45 lbs. pressure above the atmosphere, which is equal to 60 lbs. pressure above a perfect vacuum (the pressure of the atmosphere being considered as equal to 15 lbs. on the square inch), and a terminal pressure of 5 lbs., we get 12 expansions, because the pressure at the end of the stroke is 12 times less than what it was at the point off cut-off, and is expressed by the formula—

$$\frac{P}{t} = R.$$

Where $P =$ pressure at point of cut-off, $t =$ terminal pressure, and $R =$ ratio or number of expansions, and as the pressure of

steam, according to Marriotte's law, varies inversely as the space it occupies, the steam will now fill 12 times the space it originally occupied at a pressure equal to $\frac{1}{12}$th of the original pressure, that is, supposing there had been no loss of heat during the process of expansion, and this we must suppose to simplify this inquiry.

On reference to the annexed table of average pressures, it will be seen that steam admitted at 60 lbs. pressure, and cut-off at $\frac{1}{12}$th part of the stroke, exerts an average pressure = 17.32 lbs. per sq. in. on the piston throughout the whole stroke, and, although this is 3½ times less work than would have been done had the steam been used at the full pressure of 60 lbs. throughout the whole length of the stroke, still only a 12th part of the cylinder's contents had been filled from the boiler, and the power required is thus got by working the steam expansively, at a saving equal to about 3½ to 1. (See Table A.)

Steam cut off at	Pressure in Lbs. at Com- 30	35	40	45	50	55	60
1/3	21	24½	28	31½	35	38½	42
2/3	28¼	32¾	37½	42	46¾	51½	56¼
1/4	17¾	20¾	23¾	26¾	29¾	32¾	35¾
1/2	25¼	29½	33¾	38	42¼	46½	50¾
3/4	28¾	33½	38½	43¼	48¼	53	57¾
1/5	15½	18¼	20¾	23½	26	28½	31¼
2/5	23	26¾	30½	34½	38¼	42	46
3/5	27	31½	36¼	40¾	45¼	49¾	54¼
4/5	29¼	34¼	39	44	49	53¾	58½
1/6	14	16¼	18½	20¾	23¼	25½	27¾
5/6	29½	34½	39½	44¼	49¼	54	59
1/7	12⅛	14¾	16¾	18¾	21	23¼	25¼
2/7	19¼	22½	25¾	28¾	32	35¼	38½
3/7	23¾	27¾	31½	35½	39½	43½	47½
4/7	26¼	31¼	35½	40	44½	49	53½
5/7	28½	33½	38¼	42¾	47¾	52½	57¼
6/7	29½	34½	39½	44½	49½	54¼	59¼
1/8	11½	13½	15¼	17¼	19¼	21¼	23
3/8	22¼	26	29¾	33½	37	40¾	44½
5/8	27½	32	36¾	41¼	45½	50½	55¼
7/8	29¾	34¾	39½	44½	49½	54½	59½
1/9	10½	12¼	14¼	15¾	17¾	19½	21¼
2/9	16½	19¼	22¼	25	27¾	30½	33¼
4/9	24	28	32	36	40¼	44¼	48½
5/9	26¼	30¾	35¼	39½	44	48½	52¾
7/9	29	34	38¾	43¾	48½	53½	58¼
8/9	29¾	34¾	39¾	44½	49½	54½	59½
1/11	9¼	10¾	12¼	13¾	15¼	16¾	18½
2/11	14¾	17¼	19½	22	24½	27	29½
3/11	18¾	21¾	25	28	31¼	34¼	37½
4/11	21¾	25½	29¼	32¾	36½	40¼	43¾
5/11	24¼	28¼	32½	36¼	40½	44½	48¾
6/11	26¼	30½	35	39¼	43¾	48	52½
7/11	27½	32¼	36¾	41½	46	50¾	55½
8/11	28¾	33½	38¼	43	47¾	52¾	57½
9/11	29¼	34¼	39¼	44	49	54	58¾
1/12	8½	10	11½	13	14½	15¾	17¼

OF EXPANSION.

mencement of Stroke.

65	70	75	80	85	90	95	100
45½	49	52½	56	59½	63	66½	70
61	65½	70¼	75	79½	84½	89	93¾
38¾	41¾	44¾	47¼	50¾	53¼	56¼	59¼
55	59½	63½	67¾	72	76½	80½	84¾
62½	67½	72¼	77¼	82	87	91¼	96½
34	36½	39	41¾	44¼	47	49½	52¼
49¾	53½	57½	61¼	65	69	72¾	76½
58¾	63¼	67¾	72½	77	81½	86	90½
63½	68½	73¾	78¼	83	88	92¾	97¾
30½	32½	34¾	37¼	39½	41¾	44¼	46½
64	69	73¾	78¾	83¾	88¼	93½	98½
27¼	29½	31½	33½	35¾	37¾	40	42
41¾	45	48¼	51½	54½	57¼	61	64¼
51½	55¼	59¼	63¼	67¼	71¼	75¼	79
57¾	62½	66¾	71¼	75¾	80	84½	89
62	66¾	71½	76¼	81	85¾	90¼	95½
63¾	69¼	74¼	79	84	89	93¾	98¾
25	27	28¾	30¾	32¾	34½	36½	38½
48¼	52	55¾	59½	63	66¾	70½	74¼
59¾	64½	68¾	73½	78	82½	87¼	91¾
64½	69¼	74¼	79¼	84¼	89¼	94¼	99
23	24¾	26½	28¼	30¼	31¾	33¾	35½
36	38¾	41¾	44½	47¼	50	52¾	55½
52¼	56¼	60¼	64¼	68¼	72¼	76¼	80½
56½	61¾	66	70½	74¾	79¼	83¾	88
63¼	68	72¾	77¾	82¾	87½	92¼	97¼
64½	69½	74½	79¼	84¼	89¼	94¼	99¼
20	21½	23	24½	26¼	27¾	29¼	30¾
31¾	34¼	36¾	39¼	41¾	44¼	46¾	49
40¾	43¾	47	50	53¼	56¼	59½	62½
47½	51	54¾	58½	62	65¾	69½	73
52¾	56¾	60¾	65	69	73	77	81¼
56¾	61¼	65½	70	74¼	78¾	83	87½
60	64½	69¼	73¾	78½	83	87¾	92¼
62¼	67	71¾	76¾	81½	86¼	91	95¾
63¾	68¾	73½	78½	83½	88¼	93¼	98¼
18¾	20¼	21¾	23¼	24½	26	27½	29

Average Pressure in Lbs. upon the Piston.

TABLE A.—Continued.

Steam cut off at	Pressure in Lbs. at Commencement of Stroke—				
	110	120	120	140	150
$\frac{1}{3}$	77½	84	91	98	105
$\frac{2}{3}$	103	111½	121¾	131	140½
$\frac{1}{4}$	65½	71½	77½	83½	89½
$\frac{1}{2}$	93¼	101½	110	118½	127
$\frac{3}{4}$	106¼	115¾	125½	135¼	144¾
$\frac{1}{5}$	57¼	62½	67¾	73	78½
$\frac{2}{5}$	84¼	91¾	99½	107¼	115
$\frac{3}{5}$	99½	108¾	117¾	126¾	135
$\frac{4}{5}$	107½	117½	127¼	136¾	146¾
$\frac{1}{6}$	51¼	55¾	60½	65	69¾
$\frac{5}{6}$	108¼	118¼	128	137¾	147
$\frac{1}{7}$	46¼	50½	54¾	58¾	63
$\frac{2}{7}$	70¾	77¼	83½	90	96½
$\frac{3}{7}$	87	94¼	102¼	110¾	118¾
$\frac{4}{7}$	98	106¾	115¾	124¾	133½
$\frac{5}{7}$	105	114¼	124	133½	143¼
$\frac{6}{7}$	108¾	118¾	128½	138½	148¼
$\frac{1}{8}$	42¾	46¼	50	54½	57¾
$\frac{3}{8}$	81¾	89	96½	104	111½
$\frac{5}{8}$	101	110¼	119½	128½	137¾
$\frac{7}{8}$	109	119	128¾	138¾	148¾
$\frac{1}{9}$	39	42½	46	49½	53¼
$\frac{2}{9}$	61	66¾	72¼	77¾	83
$\frac{4}{9}$	88½	96½	104½	112½	120½
$\frac{5}{9}$	97	105¾	114½	123¼	132¼
$\frac{7}{9}$	107	116¾	126½	136¼	145
$\frac{8}{9}$	109¼	119¼	129	139	149
$\frac{1}{11}$	33¾	37	40	43¼	46¼
$\frac{2}{11}$	54	59	63¾	68¾	73¾
$\frac{3}{11}$	68¾	75¼	81½	87¾	94
$\frac{4}{11}$	80¼	87¾	95	102¼	109½
$\frac{5}{11}$	89¼	97½	105½	113¾	121¾
$\frac{6}{11}$	96¼	105	113¾	122½	131
$\frac{7}{11}$	101½	110¾	120	129¼	138½
$\frac{8}{11}$	105¼	115	124½	134¼	143½
$\frac{9}{11}$	108	117¾	127½	137½	147¼
$\frac{1}{12}$	31¾	34¾	37¾	40½	43½

Average Pressure in Lbs. upon the Piston.

As the point of cut-off may be different from any of those shown in the table, it is as well that the student should be in possession of a simple formula for ascertaining the average pressure for himself at any time, and the following is given to find out the mean pressure during a stroke in lbs. per sq. in. Let—

L = Whole length of stroke in inches.
l = Distance travelled by piston before the steam is cut off, in inches.
R = Ratio or number of expansions = $\frac{L}{l}$.
H = Hyperbolic logarithm of R.
P = Initial pressure of steam in lbs. per sq. in.
p = Mean pressure during the stroke in lbs. per square inch.

Then, $p = P\,\frac{1 + H}{R}$.

A table of hyperbolic logarithms is also annexed so that H may be found without any difficulty.

TABLE OF HYPERBOLIC LOGARITHMS.

The Hyperbolic Logarithm of a number is found by multiplying the common Logarithm of the number by 2.30259.

No.	Logarithm.
1–1	.0953102
1–2	.1823215
1–3	.2623642
1–4	.3364722

No.	Logarithm.
1-5	.4054652
1-6	.4700036
1-7	.5306282
1-8	.5877866
1-9	.6418538
2-0	.6931472
2-1	.7419373
2-2	.7884573
2-3	.8329090
2-4	.8754686
2-5	.9162907
2-6	.9555113
2-7	.9932518
2-8	1.0296913
2-9	1.0647107
3-0	1.0986124
3-1	1.1314021
3-2	1.1631508
3-3	1.1939224
3-4	1.2237754
3-5	1.2527629
3-6	1.2809338
3-7	1.3083328
3-8	1.3350010
3-9	1.3609765
4-0	1.3862943
4-1	1.4109869
4-2	1.4350845
4-3	1.4586149
4-4	1.4816045
4-5	1.5040773
4-6	1.5260563
4-7	1.5475625
4-8	1.5686159
4-9	1.5892352
5-0	1.6094379
5-1	1.6292405
5-2	1.6486586
5-3	1.6677068
5-4	1.6863989
5-5	1.7047481
5-6	1.7227665
5-7	1.7404661

No.	Logarithm.
5–8	1.7578579
5–9	1 7749523
6–0	1.7917595
6–1	1.8082887
6–2	1.8245493
6–3	1.8405496
6–4	1.8562979
6–5	1.8718021
6–6	1.8870697
6–7	1.9021075
6–8	1.9169226
6–9	1.9315214
7–0	1.9459100
7–1	1.9600947
7-2	1.9740810
7–3	1.9878743
7–4	2.0014800
7–5	2.0149030
7–6	2.0281482
7–7	2.0412203
7–8	2.0541237
7-9	2.0668627
8–0	2.0794414
8–1	2.0918640
8-2	2.1041341
8–3	2 1162555
8–4	2 1282317
8-5	2.1400661
8–6	2.1517622
8–7	2.1633230
8-8	2 1747517
8–9	2.1860512
9–0	2.1972245
9–1	2.2082744
9-2	2.2192034
9–3	2.2300144
9–4	2.2407096
9–5	2.2512907
9–6	2.2617631
9–7	2.2721258
9–8	2 2823823
9–9	2.2925347
10–0	2.3025851

No.	Logarithm.
11–0	2.3978953
12–0	2.4849066
13–0	2.5649494
14–0	2.6390572
15–0	2.7080502
16–0	2.7726067
17–0	2.8332841
18–0	2.8903847
19–0	2.9444497
20–0	2.9957322
21–0	3.0445437
22–0	3.0910562
23–0	3.1354964
24–0	3.1780715
25–0	3.2188757
26-0	3.2581099
27–0	3.2958495
28–0	3.3322306
29–0	3.3672992
30-0	3.4011974

In order to arrive at the merits and capabilities of the compound engine, let us first see what are the results got from a single-cylinder condensing engine of given dimensions and cutting off the steam to work with a certain number of expansions. Let—

D = Diameter of cylinder in inches,
L = Length of stroke in feet,
N = Number of revolutions of crank per minute,
p = Mean or average pressure on piston,

then, for arriving at the horse power we use the following formula:—

$$\frac{D^2 \times .7854 \times 2\,L \times N \times p}{33.000} = \text{horse-power.}$$

But as $D^2 \times .7854$ = area of piston, and $2\,L \times N$ = speed of piston in feet per minute, we will make $D^2 \times .7854 = A$, and $2\,L \times N = S$, the formula then becomes

$$\frac{A \times S \times p}{33.000} = \text{H. P.}$$

and supposing the cylinder to be 24 in. diameter, length of stroke=4 ft.; number of revolutions per minute=50; pressure of steam at beginning of stroke=60 lbs. (all pressures here mentioned are above a perfect vacuum), point of cut-off, $= \frac{1}{12}$th part of the stroke, or, after the piston has travelled 4 in., so that—

$D = 24$ inches.
$2\,L = 8$ feet.
$N = 50$ revolutions.
$P = 60$ lbs.
$p = P\,\frac{1 \times H}{R} = 17.32$, we get—

$$\frac{452.4 \times 400 \times 17.32}{33.000} = 95 \text{ horse-power;}$$

To distribute this power equally over the working parts of a compound engine, it is

desirable that both cylinders be so proportioned that they will each give out nearly the same power, and that the thrust caused by the entrance of the steam at the beginning of each stroke be the same in both cylinders.

To attain this with an accuracy sufficient for all practical purposes, it is necessary that the condensing cylinder be larger than the high-pressure cylinder in area, by the ratio of expansion that takes place in the high-pressure cylinder; that is to say, if

a = area of piston in high-pressure cylinder,
r = ratio of expansion in high-pressure cylinder,
A = area of piston in condensing cylinder, then

$$A = a\,r.$$

So that if P = initial pressure in small cylinder, and P′ = initial pressure in large cylinder, the area of large piston, multiplied by P′, will be equal to the area of small piston multiplied by P, then $P'\,A = P\,a$.

But as the ratio of expansion is the same in both cylinders, and the whole ratio of expansion equal to the initial pressure in small cylinder, divided by the terminal

pressure in large cylinder, we get $\sqrt{\frac{P}{t}} =$ ratio of expansion in each cylinder, and as we have already taken P=60 lbs., and $t =$ 5 lbs., we have $\sqrt{\frac{60}{5}} = 3.46 =$ differences of area of the two pistons, and also ratio of expansion in each cylinder, and consequently $= r$.

From the nature of the compound engine, the area opened up for the steam by the movement of the large piston is at all times decreased by a proportionate part $= \frac{A}{a\,r}$ $= 1$, by the advancing area of small piston, so that the space actually occupied by the expanding steam is $= A - 1$, and from this we get the formula for ascertaining the average pressure in the condensing cylinder of a compound engine.

$$p' = P' \frac{H}{R - 1.}$$

A table showing the relative areas of the two cylinders of a compound engine, with the average pressure in each cylinder, etc.:

P	R	P′	H	S	p′	p
30	2.449	12.25	.896	23.23	7.52	15.71
35	2.645	13.22	.972	26.10	7.83	18.27
40	2.828	14.14	1.040	28.85	8.04	20.81
45	3.000	15.00	1.098	31.47	8.22	23.25
50	3.162	15.86	1.150	34.00	8.40	25.60
55	3.316	16.58	1.197	36.44	8.58	27.86
60	3.464	17.32	1.242	38.83	8.74	30.09
65	3.605	18.02	1.281	41.13	8.85	32.28
70	3.741	18.70	1.319	43.39	9.08	34.31
75	3.872	19.36	1.353	45.57	9.11	36.46
80	4.000	20.00	1.386	47.72	9.24	38.48
85	4.123	20.61	1.415	49.78	9.34	40.44
90	4.242	21.21	1.444	51.85	9.44	42.41
95	4.358	21.80	1.470	53.84	9.56	44.28
100	4.472	22.36	1.497	55.84	9.64	46.20
105	4.582	22.91	1.521	57.77	9.73	48.04
110	4.690	23.45	1.545	59.69	9.82	49.87
115	4.795	23.98	1.567	61.57	9.89	51.68
120	4.898	24.45	1.589	63.43	9.96	53.47
125	5.000	25.00	1.609	65.32	10.05	55.27
130	5.099	25.50	1.629	67.02	10.13	56.89
135	5.196	26.00	1.647	68.77	10.21	58.66
140	5.291	26.46	1.665	70.51	10.26	60.25
145	5.385	26.93	1.688	72.25	10.32	61.93
150	5.477	27.38	1.700	73.95	10.38	63.57
155	5.567	27.84	1.716	75.67	10.46	65.21
160	5.656	28.32	1.732	77.28	10.52	66.76
165	5.744	28.72	1.748	78.93	10.58	68.35
170	5.830	29.15	1.763	80.56	10.64	69.92
175	5.916	29.58	1.777	82.14	10.70	71.44
180	6.000	30.00	1.791	83.73	10.75	72.98
185	6.082	30.41	1.805	85.32	10.80	74.52
190	6.164	30.82	1.818	86.86	10.85	76.91

The accompanying table has been drawn out for easy reference in conformity with this rule. The first column $=$ P $=$ the initial pressure of the steam above a perfect vacuum on entering the small cylinder; the second $= R = \sqrt{\frac{P}{t}}$ shows the relative areas of the two cylinders, and also the number of expansions in high-pressure cylinder; the third column, $= P =$ the terminal pressure in high-pressure cylinder, gives the pressure at beginning of stroke in condensing cylinder; the fourth column, $=$ H, contains the hyperbolic logarithms of R; the fifth, $=$ S, gives the average pressure during a stroke in a single cylinder, for the different values of R and $= P\,\frac{1+H}{R}$; the sixth column, $= p'$, gives the average pressure during a stroke in the condensing cylinder of a compound engine, and $= P'\frac{H}{R-1}$ and the last column, p, gives the average pressure during a stroke in the high-pressure cylinder $P = \frac{1+H}{R} - P'\,\frac{H}{R-1}$.

Now, as the power to be given out by both cylinders is to be the same, the power that is required to be given out by A $= \frac{95}{2} = 47.5$ horse-power, and as $\sqrt{\frac{60}{5}} = 3.464$, $t \times 3.464 = 17.32 = P'$, and from the above formula we get $p' = 17.32 \frac{H}{R-1} = 8.74$ lbs. average pressure per square inch on piston. So that we can now get what area of piston is required to give out this power by

$$\frac{47.5 \times 33.000}{400 \times 8.74} = 450 = 24'' \text{ diameter.}$$

and as the area of the two pistons are to each other as 1 to 3.464, we get the area of small piston = 130 sq. in. = 13″ diameter.

Table of the pressure, temperature, volume, and mechanical effect of steam.

Total pressure in lbs. per square inch.	Corresponding temperature.	Volume of steam compared with volume of water.	Mechanical effect of a cubic inch of water evaporated, in lbs. raised 1 ft. high.
1......	102 9	20868	1789
2......	126.1	10874	1812
3......	141.0	7437	1859
4.... .	152.3	5685	1895
5......	161.4	4617	1924
6......	169.2	3897	1948
7	175.9	3376	1969
8......	182.0	2983	1989
9......	187.4	2674	2006
10......	192.4	2426	2022
11......	197.0	2221	2036
12......	201.3	2050	2050
13......	205.3	1904	2063
14......	209.1	1778	2074
15......	212.8	1669	2086
16.. .	216.3	1573	2097
17......	219.6	1488	2107
18	222.7	1411	2117
19......	225.6	1343	2126
20......	228.5	1281	2135
21......	231 2	1225	2144
22......	233.8	1174	2152
23......	236.3	1127	2160
24......	238.7	1084	2168
25......	241.0	1044	2175
26.....	243.3	1007	2182
27......	245.5	973	2189
28......	247.6	941	2196
29......	249.6	911	2202
30......	251.6	883	2209

Total pressure in lbs. per square inch.	Corresponding temperature.	Volume of steam compared with volume of water.	Mechanical effect of a cubic inch of water evaporated, in lbs. raised 1 ft. high.
31......	253.6	857	2215
32......	255.5	833	2221
33......	257.3	810	2226
34......	259.1	788	2232
35......	260.9	767	2238
36......	262.6	748	2243
37......	264.3	729	2248
38......	365.9	712	2253
39......	367.5	695	2259
40......	269.1	679	2264
41......	270.6	664	2268
42......	272.1	649	2273
43......	273.6	635	2278
44......	275.0	622	2282
45......	276.4	610	2287
46......	277.8	598	2291
47......	279.2	586	2296
48......	280.5	575	2300
49......	281.9	564	2304
50......	283.2	554	2308
51......	284.4	544	2312
52......	285.7	534	2316
53......	286.9	525	2320
54......	288.1	516	2324
55......	289.3	508	2327
56......	290.5	500	2331
57......	291.7	492	2335
58......	292.9	484	2339
59......	294.2	477	2343
60......	295.6	470	2347
61......	296.9	463	2351
62......	298.1	456	2355
63......	299.2	449	2359

Total pressure in lbs. per square inch.	Corresponding temperature.	Volume of steam compared with volume of water.	Mechanical effect of a cubic inch of water evaporated, in lbs. raised 1 ft. high.
64......	300.3	448	2362
65......	301.3	437	2365
66......	302.4	431	2369
67......	303.4	425	2372
68......	304.4	419	2675
69......	305.4	414	2378
70......	306.4	408	2382
71......	307.4	403	2385
72......	308.4	398	2388
73......	309 3	393	2391
74......	310.3	388	2394
75......	311.2	383	2397
76......	312.2	379	2400
77......	313.1	374	2403
78......	314.0	370	2405
79......	314.9	366	2408
80......	315.8	362	2411
81......	316.7	358	2414
82......	317.6	354	2417
83......	318.4	350	2419
84.....	319.3	346	2422
85......	320.1	342	2425
86......	321.0	339	2427
87......	321.8	335	2430
88......	322.6	332	2432
89......	323.5	328	2435
90......	324.3	325	2438
91......	325.1	322	2440
92......	325.9	319	2443
93......	326.7	316	2445
94......	327.5	313	2448
95......	328.2	310	2450
96......	329.0	304	2453

Total pressure in lbs. per square inch.	Corresponding temperature.	Volume of steam compared with volume of water.	Mechanical effect of a cubic inch of water evaporated, in lbs. raised 1 ft. high.
97......	329.8	304	2455
98......	330.5	301	2457
99......	331.3	298	2460
100......	332.0	295	2462
110......	339.2	271	2486
120......	345.8	251	2507
130......	352.1	233	2527
140......	357.9	218	2545
150......	363.4	205	2561
160......	368.7	193	2577
170	373.6	183	2593
180......	378.4	174	2608

From this we can see that for a compound engine to exert the same power as a single-cylinder condensing engine with the same number of expansions in both cases, the condensing cylinder of the compound engine requires to be equal in diameter to the single condensing cylinder; and from this being the case, it is quite reasonable to say, that if the power exerted can be got from one cylinder with the steam expanded a certain number of times, it

would be unwise to add to the expense of the engine by expanding the same number of times in two cylinders instead of one. But as the source of the power obtained is the heat passed into the cylinder from the boiler, and as the economical working of the engine depends on the greatest quantity of this heat that can be converted into power, it is herein where the compound engine has the advantage over any other class of engine, and we will compare the single and the compound engine from this point of view.

The steam enters the single-cylinder engine at a pressure=60 lbs. per sq. in., the temperature of which, on reference to the annexed table, will be found to be equal to 295.6 deg. After doing its work it terminates with a pressure = 5 lbs.=161.4 deg. in temperature, and consequently has cooled down the cylinder to the same temperature, so that the fresh steam on entering to perform the next stroke can only be effective at a temperature corresponding to its pressure, and it has to part with its heat until it brings the cylinder up

to its own temperature, and has consequently to be supplied with new steam from the boiler to do its work.

Now the pressure at the beginning of the stroke of the high pressure cylinder of the compound engine is the same=60 lbs. per sq. in.; but owing to the fewer number of expansions carried out in this one cylinder, it terminates this stroke with a pressure= 17.32 lbs. per sq. in., the temperature of which will be found on reference to be 220 deg., being a difference of only 76 deg. instead of 135 deg., or just about one-half. A great part of this waste of the heat that is passed into the cylinder can be prevented by having a space round about the cylinder, and at both ends, filled with steam at the boiler pressure; but this steam jacket, as it is called, is much more effective in the compound engine than in the single cylinder engine, for this reason: It has been found from experiment that the rapidity with which two volumes of steam of different temperatures seek to equalize themselves is as the square of their difference in temperature, that is to say—that if you mix

steam of 200 deg. with steam of 100 deg., and steam of 400 deg. with steam of 100 deg., the difference of temperatures of the former being as 2 to 1, and of the latter as 4 to 1, and as $2^2=4$, and $4^2=16$; the latter temperatures will seek to equalize themselves four times quicker than the former, and, as the variation of temperature is much greater in the single cylinder than in either of the cylinders of a compound engine, the heat from the steam jacket must pass through the metal with great rapidity to replace that wasted by condensation, and this it cannot do so effectively as when the temperatures are not so widely varied; and this is one of the great advantages possessed by the compound or double-cylinder engine. Another feature in which the compound engine bears favorable comparison with the single-cylinder engine is in the difference of the thrust caused by the entrance of the steam at the beginning of each stroke, and consequently on the amount of pressure or friction thrown on the crank pin and crank shaft journals, compared with the power to be exerted. If we

multiply the area of piston in single cylinder by the initial pressure, we get $452 \times 60 = 27,120$ lbs. total pressure, or equal to a blow of fully 12 tons at the beginning of the stroke. If, in like manner, we multiply the areas of both pistons of the compound engine by their respective initial pressures we get $131 \times 60 = 7,860$ and $452 \times 17.32 = 7,828$, which being added together, gives a total pressure at beginning of stroke when both pistons are moving simultaneously$=15,688$ lbs.$=$about 7 tons or little more than one-half of that in the single cylinder, and from this it can be easily seen that as a less shock is given to the working parts by about one-half, the dimensions of these parts can be made proportionately less, and a gentler, steaddier, but equally effective motion is imparted.

The compound engine, both for marine and stationary purposes, has had the position of its cylinders and the combinations of its parts arranged in many different ways, in some cases to suit the space available for its erection, and in others, accord-

ing to the different ideas of the different manufacturers; but the principle being the same in all cases, an equal economy should be got if care is taken in so proportioning the passages for the steam that no undue obstruction is caused, and that proper and efficient means are employed to prevent any waste of heat as far as possible.

The principle of the compound engine was known as early as 1781, when a patent was taken out by Jonathan Hornblower for "Employing the steam after it has acted on the first vessel to operate a second time in the other by permitting it to expand itself." But Hornblower was never able to carry out the principle to be of much practical use, owing to Watt's patents being in existence at the time.

The earliest compound engine in which the principle was practically carried out was patented in 1804 by Arthur Woolf, and his style of engine has been in use almost ever since that date in France and the Continent generally, and is still constructed by many engineers in this country, and is known as "Woolf's Engine," and employed for sta-

tionary purposes only. Both the cylinders are placed together at one end of the walking beam, the condensing cylinder being at the outer end, and the high-pressure cylinder close up to it with a proportionately less stroke. This arrangement is perfectly capable of carrying out the principle equal to any other. But the great pressure it exerts on the main centre of the walking beam, owing to all the power requiring to pass from the one end of the beam to the other, has caused it to be less extensively used than otherwise might have been the case; but more especially since 1845, when a patent was taken out by Wm. McNaught, wherein this great pressure is removed from the main centre by having the condensing cylinder only at the outer end of beam, and the high-pressure cylinder between the main centre and the crank, thus having the power equal on both sides of the main centre, and the pressure consequently merely nominal at that part. This arrangement is by far the best when the engine has to be of the walking-beam class.

Another good arrangement is carried out

in horizontal engines, with both cylinders lying side by side (generally cast together in one piece), and secured to a single sole plate; both piston rods are attached to one crosshead, so that one connecting rod conveys the whole power to the crank, nothing being in duplicate but the cylinders.

In the compound engine at present so largely employed in the British Navy, the cylinders, outwardly, are the same diameter, but the high-pressure cylinder, as previously mentioned, is generally made about $\frac{1}{3}$ less in area than the condensing cylinder. The space round the actual high-pressure cylinder being used to receive its exhaust steam until the valve of condensing cylinder opens to admit it, as the pistons do not move simultaneously, owing to the cranks being at right angles to each other.

It has been explained in the first part of this work that the nominal horse power of an engine is ascertained by assuming the mean pressure on the piston to be equal to 7 lbs. on the square inch, and the speed of piston equal to 220 ft. per minute. But as

both the working pressure and speed of piston have been greatly increased since the above rule was first adopted, it fails to convey any adequate idea of the actual capabilities of the engine. Still, in all negotiations connected with the purchase of a steam engine, it is, as a rule, the nominal horse power alone that is referred to, although it is understood that with a pressure, say of about 60 lbs., and a piston speed of about 400 ft. per minute, fully six times the nominal power is got from a condensing engine.

As the term "Nominal Horse-Power" is only used when speaking of the steam engine as a marketable commodity, a particular size of cylinder may be called a certain nominal power by one maker, and a different nominal power by another, and unfair competition often takes place by two manufacturers offering for sale say an 80 horse-power condensing engine, one of whom means to give a cylinder 50 in. diameter, whilst the other calls a 40 in. cylinder the same nominal power. The rules now generally adopted in this country to deter-

mine the nominal power of the different kinds of steam engines are as follows:—

Rule to find the nominal horse-power of a high-pressure non-condensing steam engine: Square the diameter of cylinder in inches, and divide by 12, that is to say, a non-condensing engine with a cylinder=30 in. diameter, is called a 75 horse-power engine nominal, although it is capable of giving out at least three times the power when a pressure of say 60 lbs. is employed, and piston speed=400 ft. per minute.

Rule to find the nominal horse-power of a single cylinder condensing engine: Square the diameter of cylinder in inches, and divide by 24, that is to say, that a condensing steam engine with a cylinder=30 in. diameter, is called a 37½ horse-power engine nominal, but is capable of working to at least six times its nominal power with 60 lbs. pressure and speed of piston=400 ft. per minute.

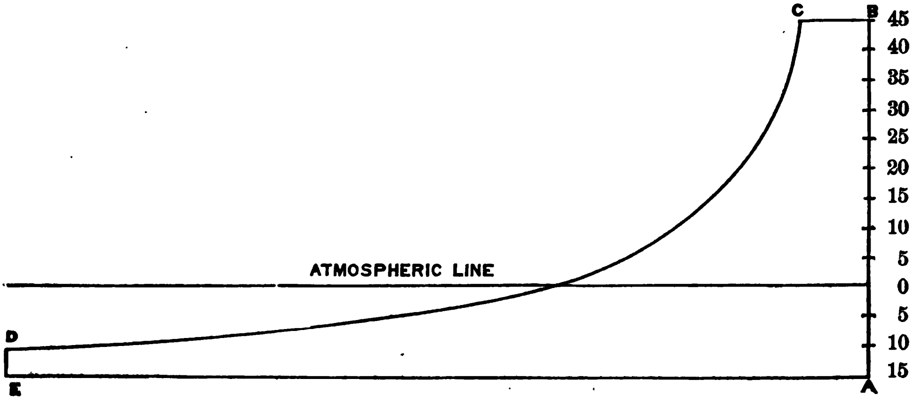
The rule now generally adopted by marine engineers for the nominal power of a compound engine is: Add the square of the

diameter of each cylinder in inches together, and divide the sum by 30, that is with a compound engine whose condensing cylinder is 30 in. diameter, and high-pressure cylinder 17 in. diameter, is called a 40 horse-power compound engine nominal, and is also capable of working to at least six times that power with 60 lbs. pressure and speed of piston=400 ft. per minute.

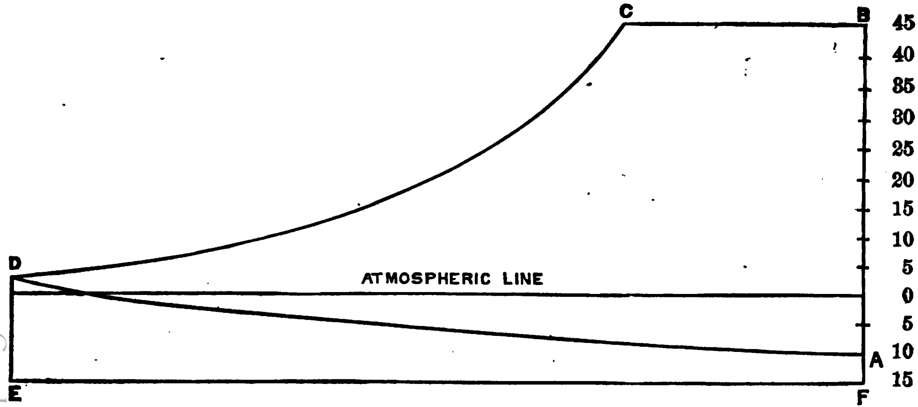
Some diagrams are herewith given, the first two of which are theoretical, and the shape that would actually be got was there no loss of heat during the stroke from condensation or other causes. In the theoretical diagram, showing the expansion curve when the steam is expanded 12 times in a single cylinder condensing engine, A B represents the total initial pressure of 60 lbs., B C the constant supply of steam from the boiler at that pressure, C the point where the steam is entirely shut off=$\frac{1}{12}$th part of the stroke, C D the expansion curve formed by the decreasing pressure of the steam in the ratio that the space it occupies is increased by the advance of the piston, D E represents the terminal pressure, and E A

the line of perfect vacuum. In the compound theoretical diagram, C D is the expansion curve formed from the high-pressure cylinder, and D A the expansion curve formed from the condensing cylinder, the line F B representing the initial pressure of 60 lbs., D E the terminal pressure in high-pressure cylinder, and initial pressure in low-pressure cylinder, and equal to 17.32 lbs., and F A the terminal pressure in low-pressure cylinder, and equal to 5 lbs.

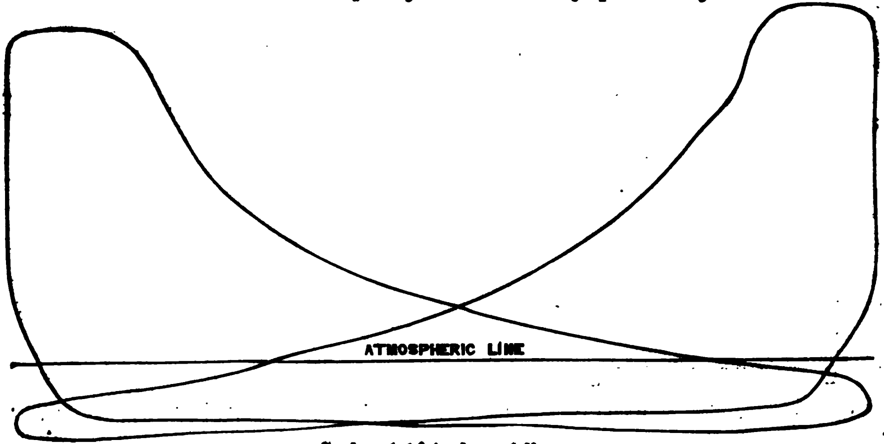
A Theoretical Diagram showing the Expansion Curve in a Single Cylinder Condensing Engine, with Steam at 60 lbs. pressure above a perfect vacuum, expanded 12 times.



Theoretical Diagrams showing the Expansive Curve in both Cylinders of a Compound Engine, with Steam at 60 lbs. pressure above a perfect vacuum. Total number of expansions = 12.

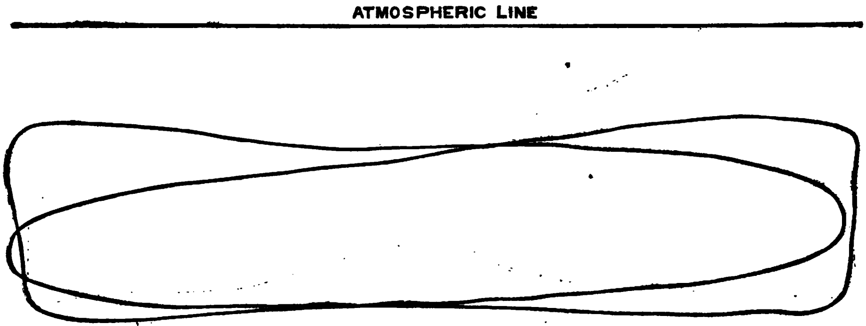


HIGH PRESSURE.—*Diagrams taken from a Compound Engine with Steam cut-off after the Piston has travelled one-eighth of the stroke in high-pressure Cylinder.*



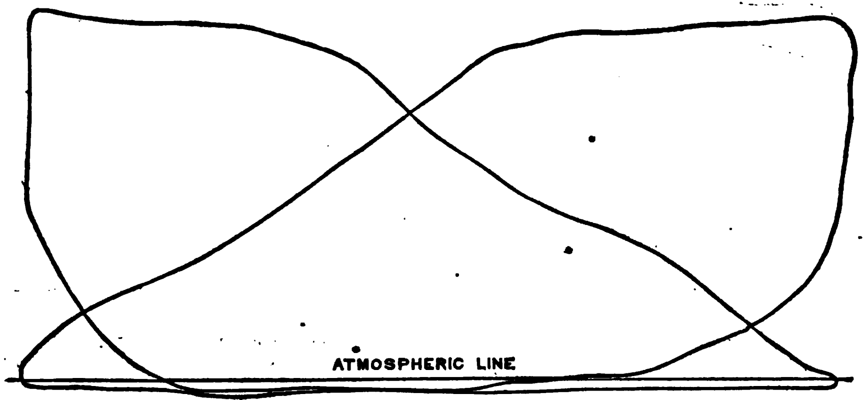
Scale—1-´6 inch = 1 lb.

Low Pressure.—*Diagrams taken from a Compound Engine with Steam cut-off after the Piston has travelled one-eighth of the stroke in high-pressure Cylinder.*



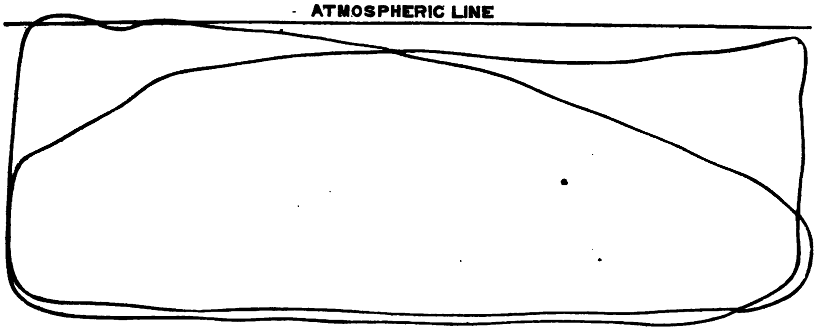
Scale – 1-8th inch = 1 lb.

High Pressure.—*Diagrams from the Compound Engine of the S. S. "Dunluce Castle"—Steam cut-off at one-half the stroke in high-pressure Cylinder.*



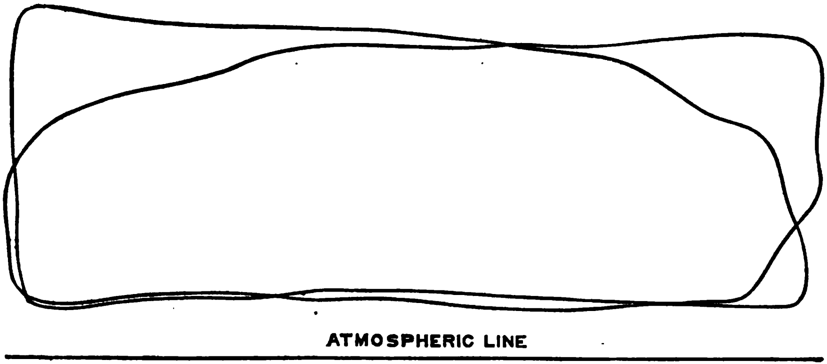
Scale—1-24th inch = 1 lb.

Low Pressure—*Diagrams from the Compound Engine of the S. S. "Dunluce Castle"— Steam cut-off at one-half the stroke in high-pressure Cylinder.*



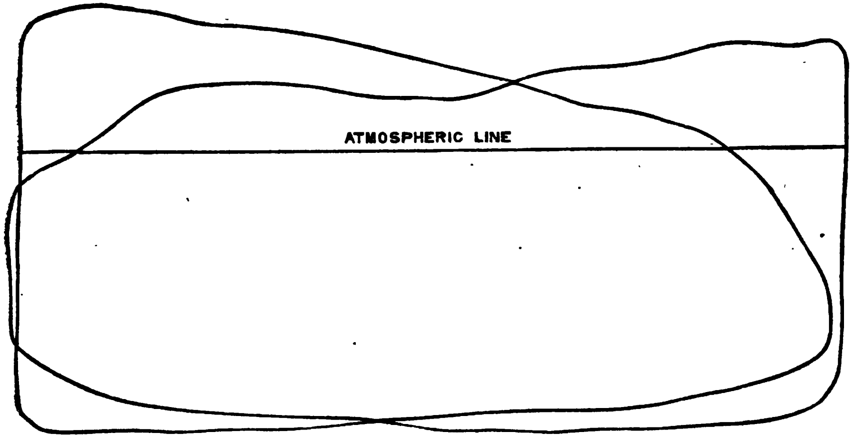
Scale—1-8th inch = 1 lb.

HIGH PRESSURE.—*Diagrams from the Compound Engine of the S. S. " Dunluce Castle, with the Link full out.*



Scale—1-24th inch = 1 lb.

[**Low Pressure.**—*Diagrams from the Compound Engine of the S. S. "Dunluce Castle," with the Link full out.*



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